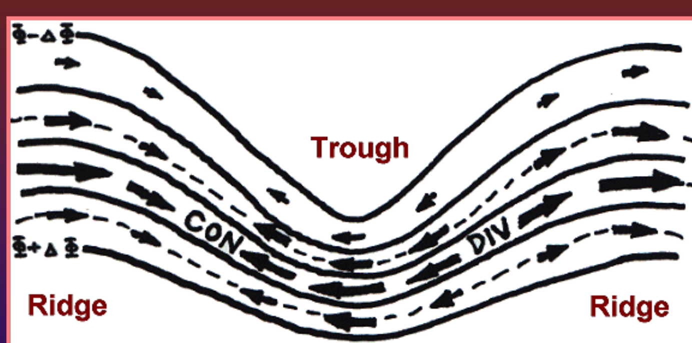
A Review of Certain Winter Weather Processes in the Atmosphere and Their Effect on Precipitation

Ted Funk

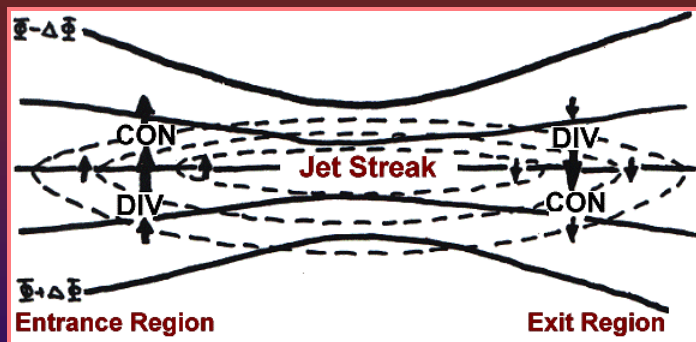
SOO, WFO Louisville

Ageostrophic Winds w/r/t Curvature



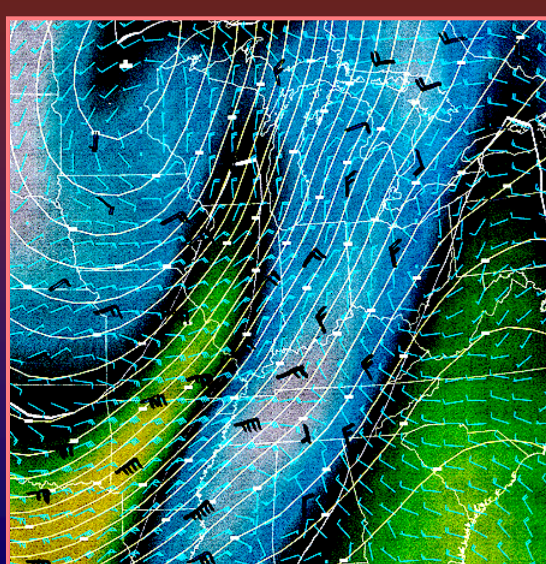
The along-stream component of the ageostrophic wind produces patterns of divergence and convergence due to curvature in the flow. Thus, a short wavelength between an amplified trough and downstream ridge usually results in strong upper-level divergence and vertical motion.

Ageostrophic Winds w/r/t Jet Streaks



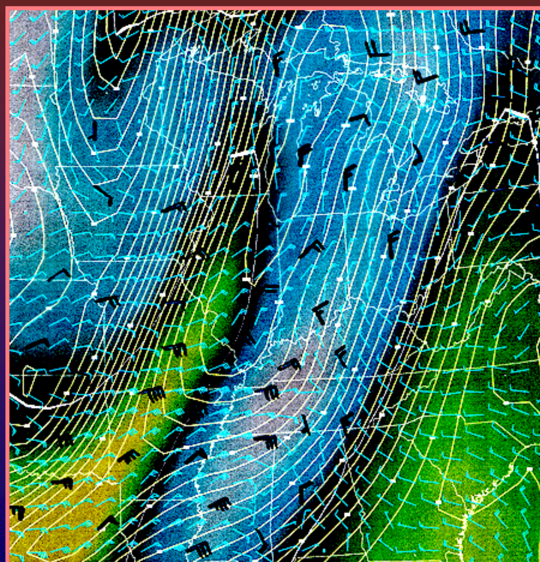
The cross-stream component of the ageostrophic wind produces patterns of divergence and convergence due to accelerations (jet entrance regions) and decelerations (jet exit regions) in the flow. The stronger the along-stream wind variation in the flow, the greater the upper-level divergence due to this component. Superimposing jet streaks and curvature enhances upper-level divergence in right entrance and left exit regions.

Ageostrophic Winds w/r/t Curvature



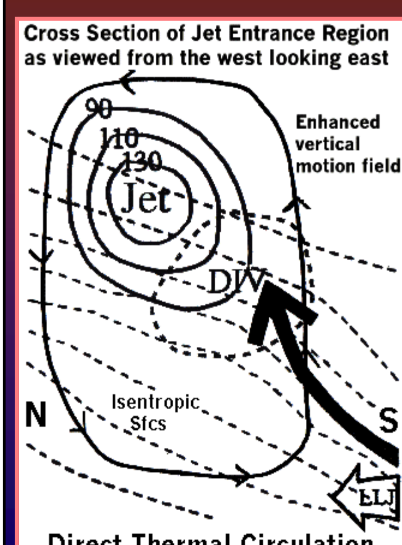
NGM 300 mb heights and total ageostrophic winds, and mean RH. Ageostrophic winds directed parallel to the height lines are due to curvature in the flow (e.g., easterly winds in the trough axis and westerly winds in the ridge axis) which creates broad divergence between the trough and the ridge. In this area of broad divergence and vertical motion, a long axis of deep-layered moisture existed.

Ageostrophic Winds w/r/t Jet Streaks



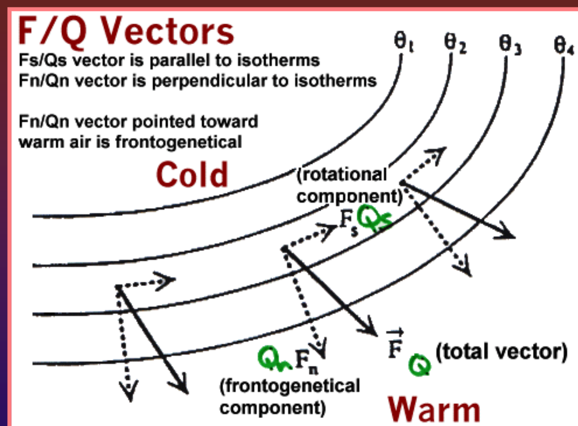
NGM 300 mb isotachs and total ageostrophic winds, and mean RH. Ageostrophic winds directed perpendicular to the isotachs (e.g., over Tennessee and Kentucky) were in response to the jet streak across the middle Mississippi Valley. Thus, upper-level divergence and vertical motion was maximized in western Kentucky and Tennessee, where the highest RH existed (white shading). Divergence in this area was due to both the along- and cross-stream components of the ageostrophic wind.

Cross Section of Jet Streak Entrance Region



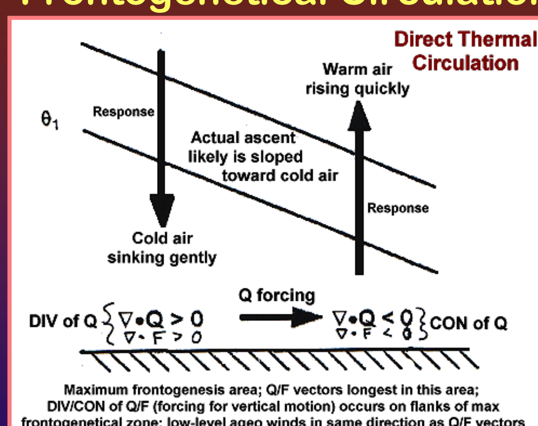
A cross section of a jet streak entrance region (looking from west to east) reveals its secondary ageostrophic direct thermal circulation (outer circle/box with arrows). Isentropes slope upward from south to north toward the jet streak. An enhanced low-level jet (LLJ) rises isentropically toward the divergence region in the right entrance region. The lower branch of the ageostrophic circulation "flows" from colder to warmer air counteracting the ambient southerly low-level flow. This creates convergence and frontogenesis in the low-to-middle levels beneath the entrance region. The resultant smaller-scale frontogenetical circulation complements the jet streak dynamics. This can lead to enhanced ascent and a band of heavy precipitation within the overall precipitation shield.

F and Q Vectors



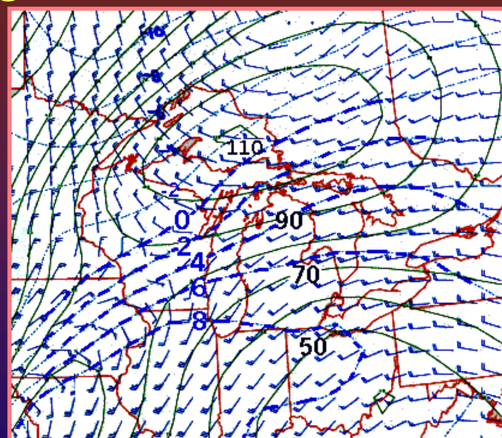
Frontogenesis is a fundamental process in the atmosphere that can result in an enhanced axis of vertical motion and banded precipitation. F/Q vectors can assess this. Fn (Fs) is the frontogenetical (rotational) component of F directed perpendicular (parallel) to isotherms/thicknesses. Frontogenesis is a maximum where Fn/Qn vectors are longest and pointed from cold to warm air. Forcing for lift occurs in F/Q convergence areas.

Frontogenetical Circulation



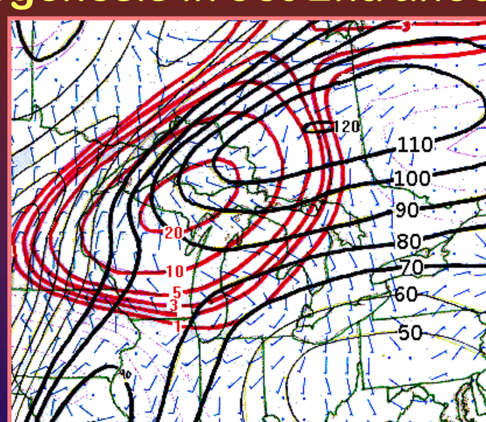
Frontogenesis produces a direct thermal circulation that is sloped with height toward cold air. F/Q vector convergence (forcing for lift) occurs on the southern/eastern periphery of the maximum frontogenesis area. A steeply sloped frontogenetical zone in the low-to-middle levels can produce a definitive band of heavy precipitation superimposed on broader, lighter precipitation.

Frontogenesis in Jet Entrance Regions



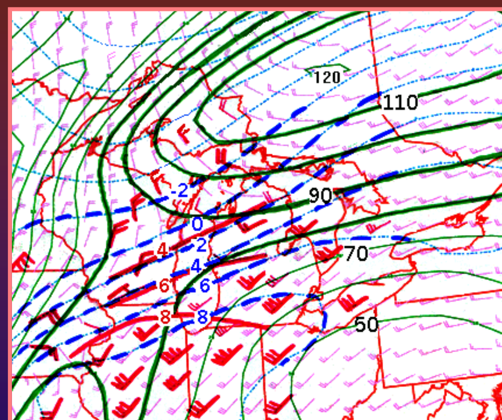
NGM forecast of 300 mb isotachs and 850 mb temps and winds. Note southerly winds and warm advection across southern Wisconsin, southern Michigan, northern Illinois, and northern Indiana. The low-level thermal gradient is within the right entrance region of the upper-level jet streak.

Frontogenesis in Jet Entrance Regions



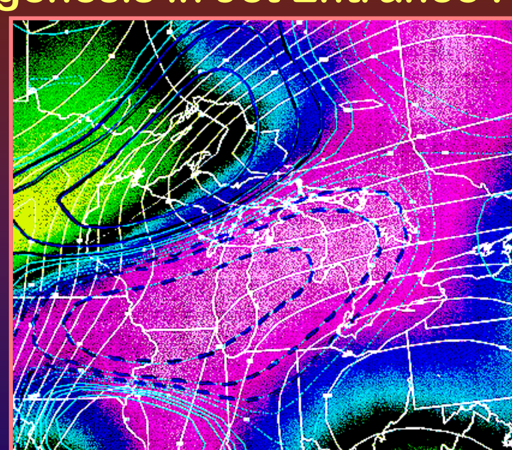
NGM 300 mb isotachs (black), 700 mb QG frontogenesis (red), and 850 mb ageostrophic winds. Note that the maximum frontogenesis is within the jet entrance region. The lower branch of the ageostrophic circulation in the entrance region tends to cause convergence within the right entrance region, resulting in forcing for lift on the southern edge of the maximum frontogenesis area.

Frontogenesis in Jet Entrance Regions



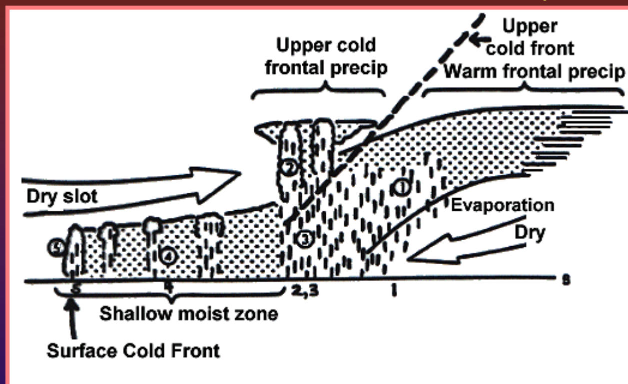
Later, the NGM forecast showed a stronger jet streak (and associated upper-level divergence) resulting in stronger 850 winds. However, 850 mb temps (blue) had actually cooled from 6 hours earlier (red lines) across southern Wisconsin, Michigan, and northern Illinois. Strong frontogenetical forcing and lift overcame the warm advection resulting in a net cooling. Heavy precipitation may occur in this area.

Frontogenesis in Jet Entrance Regions



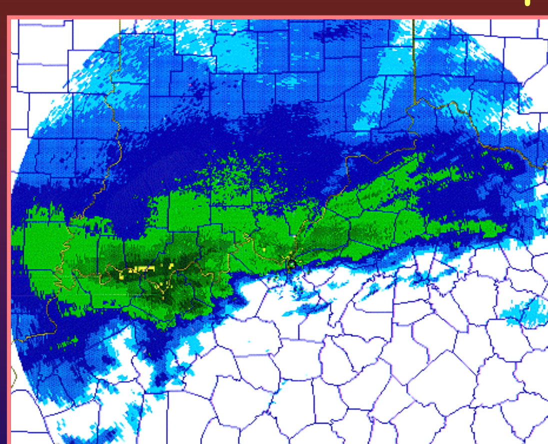
NGM 300 mb isotachs (white lines), mean RH, and 850-700 mb Qn divergence. Convergence of Qn (dashed blue) occurs within the right entrance region and southern edge of the maximum frontogenesis where strong lift and deep moisture are present. Divergence of Qn (solid blue) and forcing for descent occur in the left entrance region.

Fronts Aloft: Effect on Precipitation



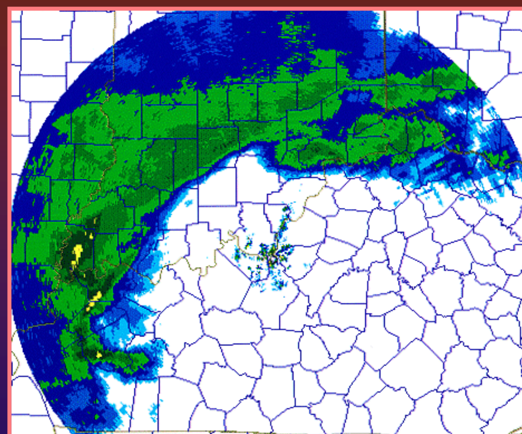
Elevated cold/warm fronts and frontogenetical zones are very important in the cool season, more so than surface boundaries, in their effect on precipitation. Typically, steady or banded precipitation occurs along and ahead of an elevated boundary, with lighter, spottier, or no precipitation behind the elevated boundary. Model data can suggest the presence of elevated boundaries. Radar data clearly shows banded precipitation associated with such features for use in short-term forecasts.

Radar Indicated Banded Precipitation



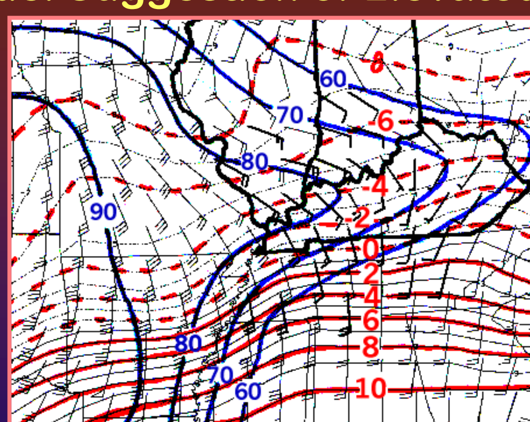
KLVX radar data at 1401 UTC 12/13/00 showed a definitive band of moderate to heavy snow along the Ohio River moving northward, with a sharp cutoff to no precipitation just to the south. The band apparently was associated with an elevated frontogenetical warm front, as surface winds were easterly over all of Kentucky with temps in the 20s.

Radar Indicated Banded Precipitation



By 1639 UTC 12/13/00, the band of moderate to heavy snow had pivoted northward over southern Indiana. The very sharp cutoff of precipitation indicated the presence of a noteworthy elevated warm front/frontogenetical zone. South of this band, warmer air surged northward aloft, despite easterly surface winds and temps in the 20s. When precipitation re-started by late afternoon (from the west), only freezing rain occurred.

Model Suggestion of Elevated Front



ETA model data at 12 UTC 12/13/00 showing mean RH (blue), and 850 winds and temps (red). The ETA suggested the presence of an elevated warm front by its axis of higher mean RH across northern Kentucky/southern Indiana and the shift in 850 mb winds around the 0 to –2 C isotherm. The model also depicted a tight thermal gradient, although it could not resolve the mesoscale feature completely in its thermal field.

Summary

Pattern recognition is a very useful tool for assessing synoptic and mesoscale environments associated with heavy precipitation. However, one must understand the processes that will interact in the atmosphere to actually create heavy precipitation and how it will evolve, given a recognized pattern. Fundamental processes to assess include:

- Isentropic lift/warm advection
- Jet streak dynamics
- Frontogenesis
- Elevated instability (ambient or upstream): Upright, CSI, or WSS

These processes can act together to produce vertical motion, from general ascent on a broad scale (isentropic lift) to strong ascent on a local scale (release of elevated instability), resulting in bands of heavy precipitation within an overall precipitation shield. Make sure you understand how these processes work and how to assess them in the context of a winter storm.